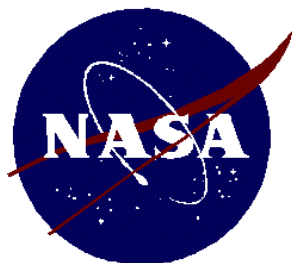


FCF Mass Properties Control Plan

Fluids and Combustion Facility

Final
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AUTHORIZED by CM when under FORMAL Configuration Control	
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PREFACE

The National Aeronautics and Space Administration (NASA) is developing a modular, multi-user experimentation facility for conducting fluid physics and combustion science experiments in the microgravity environment of the International Space Station (ISS). This facility, called the Fluids and Combustion Facility (FCF), consists of three test platforms: the Fluids Integrated Rack (FIR), the Combustion Integrated Rack (CIR), and the Shared Accommodations Rack (SAR). This document was designed to put forth a set of standardized procedures for evaluating the quarterly condition of the mass properties for each of the racks. This document also suggests some general commercial weight reduction techniques, describes what efforts have been taken to reduce the mass of each rack, and assesses the impact of reducing the mass to required levels.

**FCF MASS PROPERTIES CONTROL PLAN
FOR THE
FLUIDS AND COMBUSTION FACILITY**

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REVISION PAGE
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1.0 INTRODUCTION

1.1 Scope

The purpose of the FCF Mass Properties Control Plan is to describe the formal system that shall be implemented by the FCF project team to meet the CIR, FIR, and SAR mass properties requirements. It will describe how the Mass Properties Reports will be created. It also suggests some alternative design options for reducing the mass and maintaining the mass budget for each FCF rack through the use of a Mass Properties Report.

1.2 Use

The FCF project team shall utilize this document as the primary source for guidelines to assist them in all engineering activities related to FCF Mass Properties, such as reporting on CIR, FIR, and SAR mass properties status, maintaining a mass budget for each rack, and undertaking mass reduction measures as necessary

1.3 Responsibility

The responsibility for issuance of this report and implementation of this plan resides within FCF Systems Engineering.

1.4 Frequency

This document has been defined as a deliverable to be completed in preparation for the FCF PDR.

1.5 Upgrade

This document will be updated for SAR PDR, and as necessary to reflect any changes requested by Fluids and Combustion Facility Project Management.

2.0 DOCUMENTS

This section lists specifications, models, standards, guidelines, handbooks, and other special publications. These documents have been grouped into two categories: applicable documents and reference documents.

2.1 Order of precedence for documents.

In the event of a conflict between this document and other documents referenced herein, the requirements of this document shall apply. In the event of a conflict between this document and the contract, the contractual requirements shall take precedence over this document. All documents used, applicable or referenced, are to be the issues defined in the Configuration Management (CM) contract baseline. All document changes, issued after baseline establishment, shall be reviewed for impact on scope of work. If a change to an applicable document is determined to be effective, and contractually approved for implementation, the revision status will be updated in the CM contract baseline. The contract revision status of all applicable documents is available by accessing the CM database. Nothing in this document supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.2 Applicable documents.

The latest revision of the document below is applicable to the FCF Project to the extent specified herein.

SSP 57000 Revision E, July 21, 1999	Pressurized Payloads Interface Requirements Document
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2.3 Reference documents.

The documents below are provided only as reference material for background information and are not imposed as requirements.

NASA Goddard Space Flight Center Revision A, August 1990	Material Selection Guide
FCF-SPEC-0001 Draft 5.1, June 21, 1999	System Specifications, International Space Station Fluids and Combustion Facility

3.0 CONTROL PLAN

3.1 Control Plan Overview

The basic elements of the FCF Mass Properties Control Plan are outlined below:

1. FCF Mass Allocation and Budgeting.
2. General commercial weight reduction techniques.
3. Weight reduction efforts.
4. Impact Assessment of reducing mass to required levels.

3.2 Rack Level Mass Properties Report Tables

On a quarterly basis, the FIR, CIR, and SAR Rack Mass Managers shall be responsible for collecting CIR, FIR, and SAR Mass Property Tables from the project teams. Table I identifies the mass and center of mass data format that will be contained in the Mass Properties Tables. It is desirable to show mass data down to the component level for CIR, FIR, and SAR.

TABLE I. CIR, FIR, or SAR Mass Properties Table Format

Hardware Element	Unit Mass (Kg)	Quantity	Base Est. (Kg)	Control Factor	Center of Mass			Source Code	Notes
					X	Y	Z		
Subsystem									
Assembly									
Component									
Totals									

The project team obtained the mass by one of the following techniques:

1. Actual weighing of a component or part;
2. Making an engineering estimating of the mass by comparing the component to similar items or estimating component volume and density to calculate an estimated mass;
3. Data provided by a vendor;
4. Using data provided in literature, or calculating the mass from computer generated design.

Table II contains Source Codes used to identify the quality of the mass data. Each component of a particular subsystem is analyzed by one of the previous methods to arrive at a Base Estimate of the mass. There is an uncertainty associated with this base estimate. The Control Factor provides a margin due to the potential inaccuracy of the measurement. As the accuracy of the Base Estimate becomes less and less certain, the value of the Control Factor increases. When the Base Estimate Mass is based on an actual weighing of the part or component, the value is deemed reasonably accurate and the applied factor is low (~1.00 to 1.05). When Base Estimates are derived from conceptual design and the accuracy is less certain, a Control Factor as high as 1.20 may be applied. The Control Factor is determined and selected by the engineer performing the

analysis. Once the Mass Property Tables are updated they will be delivered to the FCF Mass Manager who will then form the quarterly FCF-RPT-0061 Mass Properties Report.

TABLE II. Source Codes

Source Code	Definition
m	Measured Data
e	Estimated Data
a	Data obtained by analysis
v	Data obtained from a vendor

3.3 Mass Allocation and Budgeting

After the Mass Properties Tables have been updated, and sent to the Rack Mass Managers, a summary of data will be provided in a Mass Properties Report FCF-RPT-0061. Table III identifies the format of the data that will be contained in the report. This report will be used for the mass allocation and budgeting for each of the racks. This table will only contain assembly level mass property data. Additional data contained in the table includes Control Mass, Margin, and Management Reserve data. The Control Mass is a calculated value that utilizes the Average Control Factor to arrive at a budget for each assembly. The use of the Average Control Factor in the calculations allows the assemblies with a higher mass uncertainty to receive more mass allocation. Margin is calculated by subtracting the Base Estimate from the Control Mass. Below the list of assemblies a line has been reserved to allocate 5% of the Control Mass to Management Reserve. This will allow the Rack Manager to allocate mass to selective assemblies. The amount allocated will be recorded in the Manager Allocation column.

TABLE III. CIR, FIR, or SAR Mass Summary Table Format

Assembly	Base Est. (Kg)	Percent of Total	Average Control Factor	Control Mass (Kg)	Percent of Total	Margin (Kg)	Installed During Launch?	Installed during Operation?	Manager Allocation (Kg)
Assembly 1									
Assembly 2									
Assembly ...									
Management Reserve									
Gross Totals									
Integrated Rack Limit									

Table IV is located under Table III in the Mass Properties Report. This table contains summarized data of Table III which include Launch Configuration Base and Control Mass, Operating Configuration Base and Control Mass, Rack Mass Total, and PI Fully Populated Mass Configuration. PI Fully Populated Mass Configuration includes all equipment necessary to perform a PI experiment i.e. Cameras, illumination package, Chamber Insert Assembly, Bottles and the PI Avionics Package.

The data contained in Table IV is described as PI worse case configuration. This worse case configuration contains use of all Universal Mounting Locations (UML), the largest bottles, maximum PI Chamber Insert Assembly mass allocation, ect.

See Appendix B for an example of a complete Mass Properties Summary Table.

TABLE IV. CIR, FIR, or SAR Summarized Mass Properties Data

Hardware	Mass (Kg)	Margin					
Launch Configuration Base Mass							
Launch Configuration Control Mass			Hardware	Base Mass (Kg)	Percent of Total	Control Mass (Kg)	Percent of Total
Operating Configuration Base Mass			Rack Total Mass				
Operating Configuration Control Mass			PI Fully Populated Mass Configuration				

The Mass Properties Report will also contain information on the history of the mass properties for the three racks. This information will be used to evaluate the mass properties from the past quarterly Mass Property Reports.

As the design and mass values of the racks mature more information will be added to the quarterly mass properties report as needed, for example, center of mass data for the assemblies and mass moment of inertia data.

3.4 General Weight Reduction Methods

The Package Lead has several options if they determine that the mass of the rack, assembly, or component is to exceed the Control Mass. The following options are available:

1. They can assign mass from the Management Reserve to cover any additional mass.
2. They can direct the project team to practice some general weight reduction methods.
3. They can direct the project team to redesign the component or assembly.

Before making the determination the Project Lead must determine an order of priority based on safety critical components versus non-safety critical components. If the item whose mass exceeds the Control Mass is deemed safety critical the Project Lead must determine an area where a non-safety item can be reduced in weight.

Various methods of weight reduction are provided in subsequent sections for informational purposes. An excellent resource for the selection of materials for the space program is the *Material Selection Guide, Revision A (August 1990)*. The NASA Goddard Space Flight Center published this document under the "Informal Document Series".

3.4.1 Material Elimination

In many cases, a manufactured part has excess material that is not required for structural integrity or functionality of the part. This method would typically be preceded by a structural analysis to show that after the material elimination, there is still sufficient safety margins for structural integrity. An example of this type of weight reduction would be machining grooves, or slots in a plate used as a wall of an enclosure. Additional benefits may be gained by the material removal. For instance, machining grooves would provide increased surface area that might be beneficial for heat rejection reasons. Another example might be drilling holes or machining large curves on corners of an object. Large curves benefit those items that the crew is exposed to since it ensures that there are no sharp corners or edges.

3.4.2 Material Selection

Another useful method of weight reduction would be to select an alternative material that has a higher strength per mass ratio. It is the project team's responsibility to determine if the hardware is a good candidate for composite material. Selecting alternate materials is often overlooked because some of the desirable materials are often considered to be exotic and the material and manufacturing costs excessive. But when considering the total life-cycle costs of a flight component (i.e., manufacturing, launch, use, stowage, return from orbit, etc.) it can be shown to be cost effective. A material that is an optional replacement for stainless steel, in most applications is Ti-6Al-4V Titanium Alloy. Table V shows how this Titanium alloy compares in strength to mass ratios when compared to other metallic materials. Titanium is weldable and has high resistance to corrosion and oxidation, but is difficult to machine and expensive. Titanium is typically used for aerospace structures, machined parts, prosthetic implants and chemical processing equipment.

TABLE V Strength to Weight Ratios of Various Metals Compared to Ti-6Al-4V

Material	Yield Point (20°C), Min. MPa	Density, g/cm ³	Strength/Weight Ratio (20°C)	Strength/Weight Ratio (20°C) Compared to Ti-6Al-4V
Ti-6Al-4V	830	4.42	188	1.0
Stainless Steel, 316L	210	7.94	26	.14
Stainless Steel, 410	620	7.72	45	.23
Aluminum, 6061	145	2.70	53	.28
Aluminum, 7075	503	2.70	186	.99
Monel® 400	200	8.83	23	.12
Inconel® 718	1090	8.44	129	.68
Hastelloy® C-276	355	8.89	40	.21
Copper-Nickel (90/10)	90	8.90	10	.05

Composite materials are also an excellent alternative to consider. Composite materials are a relatively new class of materials that combines two or more separate components into a form suitable for structural applications. While each component retains its identity, the new composite material displays macroscopic properties superior to its parent constituents, particularly in terms of mechanical properties and economic value. For decades, composite materials have been widely used by the aerospace and defense industries because of their superior performance properties. Composite materials are known for being strong and rigid, yet extremely lightweight; resistant to corrosion, environmental damage, and fatigue; flexible in their design applications; and capable of being formed into large, easy-to-integrate parts. Because they are so durable and can replace numerous small parts with several large ones, composite materials also have the potential to reduce processing, fabrication, and life-cycle costs. Certain properties can also be tailored into composites, such as increased wear resistance and improved acoustical, electrical, thermal, and aesthetic characteristics.

3.5 Specific Rack Level Mass Reduction

3.5.1 CIR Mass Mitigation

The following paragraphs describe the efforts undertaken by the Combustion Integrated Rack (CIR) team to meet the launch and on-orbit mass limits, while achieving the required science objectives. The CIR team has a continuing directive in place to design to the lowest possible mass.

A significant effort was put forth in the later half of 1998 to reduce the mass of the Combustion Chamber. A stress analysis was performed on the Combustion Chamber to determine the minimum average wall thickness required to withstand the Maximum Design Pressure with the

appropriate factors of safety. This resulted in a reduction from 10 mm to 6.5 mm thick. Material was removed from the bosses required to mount the replaceable windows, the exhaust pumps, the chamber fan, and the chamber door hinge. The material of the window inserts was changed from stainless steel to aluminum after it was determined that the use of a nickel finish coating would provide a similar life. These efforts reduced the mass of the chamber by approximately 25%.

The replaceable windows were examined to determine if a different material could be used to allow a reduction in the thickness of the windows. Sapphire is presently under investigation to determine its suitability as a window material from a structural standpoint. The use of Sapphire as a window material will reduce the thickness of the window to approximately half its present thickness. This would reduce the weight of each window by approximately 11 %. Fracture properties testing on sapphire is planned for October 2000 and results complete for FCF PDR.

The Optics Bench has been under scrutiny since its initial design. In September of 1997 the optics bench top plate thickness was reduced from 12mm to 10mm after determining that the Keenserts could be allowed to protrude. This reduced the mass of the plate by 16 %. A review was initiated in September 2000 to determine if a carbon fiber optics plate could be constructed. The concept of carbon fiber fabrication requires a high level of design maturity, while the dynamic and complex nature of the FCF hardware necessitates a continuous development process throughout the hardware fabrication and delivery cycle. Therefore, high cost (\$400,000), relatively low mass reduction (14.5 Kg), and schedule risk introduced by this technology discourages further investigation. An in depth analysis was completed in April of 1999 to remove structure internal to the optics plate. This resulted in the removal of some of the support ribs inside the optics bench that were deemed unnecessary by the analysis. This reduced the mass of the optics bench by 5%.

In March of 1998 the mounting pin housings were changed from steel to aluminum with an electrolyses nickel finish. This reduced the mass of the optics bench by 15%.

A project decision was made to stow the FCU, IPP, diagnostics and PI boxes. Therefore electrical boards in each of these boxes would not require ruggedizing and the electrical box structure could be redesigned to reduce mass. This saved about 11% per electrical board.

An IOP redesign effort resulted in an enclosure approximately 5 inches shorter for a volume reduction of 674 cubic inches, thereby reducing the mass of the overall unit by 8 %. A new approach to health and status data acquisition resulted in a harness reduction of approximately 200 wires internal and external to the IOP. This reduce the IOP mass a further 21 %. Another IOP redesign effort reduced the IOP electronic board count by four 6U VME cards along with the corresponding daughter cards and one seven slot 6U VME card cage and backplate. This effort reduced the overall IOP mass by 6 %.

An investigation was initiated in March of 1999 into Vespel polymers (half the mass of aluminum) for camera diagnostics. However, due to their brittle nature, it is not possible to use this material.

In June of 1999, the diagnostics packages were redesigned to incorporate a modular philosophy to reduce mass and increase the flexibility of the packages. Review is completed concerning investment casting in order to produce camera diagnostics with increased complexity, but less mass. The new design utilizes an investment casting process and the mass was reduced by 3%.

An investigation was performed in March 2000 to redesign the cooling system to eliminate the use of the seal hardware around the optics bench. The seal hardware was removed.

The Gas Supply and Distribution manifolds were re-designed to have the minimum amount of material needed to maintain structural integrity, reducing the mass of the manifolds by 52%.

The FOMA Control Unit (FCU) was designed using an aluminum skeleton structure with thin face sheets instead of a single piece construction to minimize mass. The GC Instrumentation package was also designed using the aluminum skeleton structure method. The GC Gas Supply Package was designed using manifolds to reduce the amount of support structure needed for the test and calibration bottles.

Table VI and VII list estimated impacts of making further mass reductions to the CIR. Table VI lists the estimated impacts of reducing the mass to the ISS required mass of 804 Kg, and Table VII lists the impacts of reducing the mass of 997 Kg. The table lists additional modifications to the CIR with their corresponding estimated savings in mass. Impacts to Station resources such as crew time, consumables, and stowage that some of these changes would cause are also assessed. Comments are given as to science impacts from these changes.

TABLE VI Weight Reduction to 804 Kg

MODIFICATION	ESTIMATED WEIGHT REDUCTION (KG)	SCIENCE IMPACT	CREW IMPACT
Remove ARIS from the rack	76	CIR would lose approximately 35% of the science due to micro-gravity requirements.	TBD
Only allow a maximum of 2 cameras to be configured on the optics bench at the same time	60	All experiments except C1, C2, C4 and C5 of the basis experiments list requirements for more than two simultaneous views. It is unknown whether worthwhile data could be obtained using multiple runs and different diagnostic configurations on all the other basis experiments.	Possible increase in time required for reconfiguration. Additional time to retrieve stowed diagnostics 30 minutes per occurrence
Reduce the chamber to 2/3 its present size	31	This would significantly impact all basis experiments. The chamber was designed to its present length to try and accommodate the large test sections of most of the basis experiments. Upwards of 80% of the experiments would be affected by this reduction possibly to the point of inability to perform them.	None
Replace breech lock with a "V" band	21	Increased time to access the chamber, reduces time available for configuration, reconfiguration and resource replacement. Installation of the V-band eliminates micro-gravity in surrounding area due to impacts required for correct installation.	Increase in time to open chamber. ROM estimate is an additional 40 minutes per occurrence. In addition there may be safety issues associated with this option.
Reduce FOMA to 2 full manifolds and one partial	17	The maximum gas supply flow rate would be reduced by 30 liters per minute (LPM) to 60 LPM. The diluent would be limited to primarily N ₂ although others could be provided in pre-mixed bottles with the O ₂ . This would increase the number of flow-through experiments that would be required to use recirculation instead.	Reduced maintenance. Potential for more bottle changes.
Reduce the size of the Air Thermal Control Unit and relocate it	17	This would obviously cut the amount of power that can be used by the rack in half. Limits the diagnostics packages that can be used.	None
Reduce the material required for the optics bench	15	Reduction of the optics bench could result in minor deformations of the optics mounting surface which could result in reduce alignment and quantitative data accuracy.	None

MODIFICATION	ESTIMATED WEIGHT REDUCTION (KG)	SCIENCE IMPACT	CREW IMPACT
Limit the PI to a maximum of 2 bottles in the FOMA	12	The maximum gas supply flow rate would be reduced by 30 liters per minutes (LPM) to 60 LPM. The diluent would be limited to primarily N ₂ although others could be provided in pre-mixed bottles with the O ₂ . This would increase the number of flow-through experiments that would be required to use recirculation instead.	More bottle changes required.
Reduce the mass allocated to the Chamber Insert Assembly (CIA)	10	This limitation would impact basis C1, C2, C3, C5, C6, C7, C8, and C9. Each of these experiments list a test section that would probably require support structure exceeding 30 Kg.	None
Replace rack doors with closeout panel	10	There appears to be no appreciable affect to science.	Increased time to access the CIR. Depending on the implementation an additional 20 minutes per occurrence is required
Reduce the amount of windows on the chamber to 3	10	All experiments except C1, C2, C4, and C5 of the basis experiment list requirements for more than two simultaneous views. Even these might be affected by this limitation as some experiments require back lights, therefore no run could be performed with two backlit diagnostics packages. It is unknown whether worthwhile data could be obtained using multiple runs and different diagnostic configurations on all the other basis experiments.	None
Reduce the size of the optics bench deployment mechanism due to the reduction of the overall mass	5	Reduction of the optics bench could result in minor deformations of the optics mounting surface which could result in incorrect alignment and reduced qualitative data.	None
Stow IOP and mount on optics bench	4	No evident impact to science, but a stowage location is a concern.	Additional setup time and launch stowage required. 30 minutes additional setup time
Reduce the amount allocated to the PI specific electronics box	3	This would affect basis experiments C1, C2, C3, C5, C6, C7, C8, and C9. The original weight of the PI specific electronics box was based upon the requirements of C6 and all the other experiments listed have at least the requirements of C6.	None
Change the 3 column Gas Chromatograph (GC) to a 2 column GC	2	The GC would lose certain detection capabilities such as detecting propanol, decane, benzene, and others.	None

MODIFICATION	ESTIMATED WEIGHT REDUCTION (KG)	SCIENCE IMPACT	CREW IMPACT
Window diameter reduced to 80 mm	2	This would affect basis experiment C3 due to the fact that it requires a larger aperture than 80 mm to obtain relevant data.	None
Remove the extra port added to the rear end cap	1.6	Removes axial views and port that would allow extra or unforeseen equipment to be inserted into the chamber.	None
Estimated Total Weight Savings	296.6 Kg.	TOTAL WEIGHT REMAINING BASED ON 1098.96 KG CONTROL MASS START	802.4 Kg.

Estimated Crew Time Delta's based on a 5 PI matrix

PI setup (includes V-band and closeout panel)	200 minutes
Diagnostic reconfiguration (stowed latch and diagnostics) 1 occurrence per PI	300 minutes
Increased frequency in bottle change-out	TBD
Install IOP	30 minutes(one time occurrence)
Total delta (CIR only)	530 minutes est. (8 hours and 20 minutes per year)

TABLE VII Weight Reduction to 997 Kg

MODIFICATION	ESTIMATED WEIGHT REDUCTION (KG)	SCIENCE IMPACT	CREW IMPACT
Replace breech lock with a "V" band	21	Installation of the V-band eliminates micro-gravity in surrounding area due to impacts required for correct installation. Eliminates micro-gravity environment in FCF and surround hardware for 25.3 to 49.3 hours per year based on the assumptions listed in the crew impact statement.	Increase in time to open chamber. ROM estimate is an additional 40 minutes per occurrence. The average PI has 42 test points. The assumption is that there are 2 openings per droplet or gas experiment and 1 opening per solid or liquid experiment. This results in 38 chamber openings if 5 PI's per year fly, or 74 openings if 10 PI's fly. This would result in an extra 25.3 to 49.3 hours per year increased crew time. In addition there may be safety issues associated with this option.
Removal of ~10% of chamber mass by eliminating ports	15	Removes axial views and ports that would allow extra or unforeseen equipment to be inserted into the chamber. Causes Non-compliance with following System Specification requirements: 3.8.3.3 Viewing of longitudinally Extend Combustion Phenomena 3.8.3.4 Axial Viewing of Combustion Phenomena 3.8.4.1.18 Chamber Penetrations	None
Reduce the material required for the optics bench	14	Reduction of the optics bench increases the chance of minor deformations of the optics mounting surface which would result in reduced alignment and quantitative data accuracy. Could Cause Non-Compliance with following System Specification Requirement: 3.8.6.1.5 Optics Bench Flatness	None
Allow the use of a maximum of 7 UML locations	12.8	This would directly affect the basis experiments C3, C8, C10, and C11. These experiments list as a requirement that they require 8 or more diagnostic packages.	Increases the on-orbit stowage requirement by 2 ft.³
Change two of the manifolds from stainless steel to aluminum	10.5	FOMA configurations required for some test points might be incompatible with aluminum. This also limits the freedom of selecting any bottle with any manifold.	None

MODIFICATION	ESTIMATED WEIGHT REDUCTION (KG)	SCIENCE IMPACT	CREW IMPACT
Reduce the mass allocated to the Chamber Insert Assembly (CIA)	10	This limitation would impact basis C1, C2, C3, C5, C6, C7, C8, and C9. Each of these experiments list a test section that requires support structure exceeding 30 Kg.	None
Reduce the number of windows to 6 (Assumption is that the windows will be eliminated at 3 and 9 O'clock positions.)	5.5	This impacts basis experiments C3, C10, and C11. These experiments require 8 windows. Causes Non-Compliance with following System Specification requirement: 3.8.4.1.5 Windows	Requires test point repetition and reconfiguration. Reconfiguration takes 1 hour (open door, rotate rack, install camera). Each experiment requires one re-configuration meaning 3 extra hours of crew time.
Stow IOP	4.7	No science impact.	Additional set-up time and launch stowage required. 30 minutes additional setup time. Also, increases the on-orbit stowage requirement for FCF by 2 ft.³
Limit the PI to a maximum of a mid-size adsorber cartridge	4	This would limit the amount of burn time/By-product generation. It would require more frequent change-out thereby reducing the amount of actual testing performed. Causes Non-Compliance with following System Specification requirement: 3.8.4.4 Adsorber Cartridge	Installation of two small or mid size adsorber cartridges for an experiment that requires a large cartridge would add an additional: 10 minutes to open and close the rack doors 30 minutes to retrieve and stow cartridge 10 minutes to install cartridge Total: 50 minutes per cartridge
Reduce the allocation to the PI specific electronics box	2	This would affect basis experiments C1, C2, C3, C5, C6, C7, C8, and C9. The weight of the PI specific electronics box is based upon the requirements of C6. All other experiments listed have at least the mass requirements of C6.	None
Reduce the clear aperture of the windows to 80 mm	2	This would affect basis experiment C3 due to the fact that it requires a larger aperture than 80 mm to obtain relevant data.	None
Estimated Total Weight Savings	101.5 Kg.	TOTAL EXTRA CREW TIME:	28 – 52 HOURS PER YEAR
TOTAL WEIGHT REMAINING BASED ON 1098.96 KG CONTROL MASS START	997.46 Kg.	TOTAL EXTRA STOWAGE:	4 FT.³
		PRESENT STOWAGE REQUIREMENTS:	6 FT.³ – FCF COMMON STOWAGE 4 FT.³ – CIR STOWAGE 2 FT.³ – FIR STOWAGE 2 FT.³ – SAR STOWAGE TOTAL: 14 FT.³ SYSTEM SPEC REQUIREMENT: 14 FT.³

3.5.2 FIR Mass Mitigation

FIR's equipment is still in the preliminary stages of design causing the mass estimates to be as well. However in an effort to keep the mass low, Table VIII has been developed to determine mitigation techniques applicable for use in all the rack systems.

3.5.3 SAR Mass Mitigation

At this time, the SAR design is merely conceptual. Consequently many of the design details have yet to be determined. However, early assessment concludes that SAR will contain most of the same hardware that is planned for the FIR. One exception is that the FIR diagnostic packages located on the optics bench are not supplied as standard equipment. Payload equipment is considered to be 2 double middeck lockers or 4 single lockers, a PI experiment package, or a combination of lockers/PI hardware with the total SAR payload equipment mass not to exceed 131 Kg. In order to provide for this payload mass, the mitigation techniques described above (section 3.5.2) may be applied as the SAR design develops.

TABLE VIII FIR Weight Reduction Options

MODIFICATION	Estimated Weight Reduction (KG)	SCIENCE IMPACT	CREW IMPACT
Remove ARIS from the rack	70	FIR would lose approximately 10% of the science due to micro-gravity requirements.	TBD
Reduce the size of the Air Thermal Control Unit and relocate it	17	This would obviously cut the amount of power that can be used by the rack in half. Limits the diagnostics packages that can be used.	None
Replace rack doors with closeout panel	10	There appears to be no appreciable affect to science.	Increased time to access the FIR. Depending on the implementation an additional 20 minutes per occurrence is required
Reduce the size of the optics bench deployment mechanism due to the reduction of the overall mass	5	Reduction of the optics bench could result in minor deformations of the optics mounting surface which could result in incorrect alignment and reduced qualitative data.	None
Stow IOP and mount on optics bench	4	No evident impact to science, but a stowage location is a concern.	Additional setup times and launch stowage required. 30 minutes additional setup time
Reduce the material required for the optics bench (Change T-groove to screw holes)	14	Reduction of the optics bench increases the chance of minor deformations of the optics mounting surface which would result in reduced alignment and quantitative data accuracy. Could Cause Non-Compliance with following System Specification Requirement: 3.8.6.1.5 Optics Bench Flatness	None
Stow IOP	4.7	No science impact.	Additional set-up time and launch stowage required. 30 minutes additional setup time . Also, increases the on-orbit stowage requirement for FCF by 2 ft.³
Estimated Total Weight Savings	124.7	TOTAL EXTRA CREW TIME:	1.5+ Hours

APPENDIX A ACRONYMS AND ABBREVIATIONS

A.1 Scope

This appendix lists the acronyms and abbreviations used in this document.

A.2 List of acronyms and abbreviations

Acronym	Description
ARIS	Active Response Isolation System
°C	Degrees Celsius
CG	Center of Gravity
CIA	Chamber Insert Assembly
CIR	Combustion Integrated Rack
cm ³	Cubic Centimeters
FCF	Fluids and Combustion Facility
FIR	Fluids Integrated Rack
FOMA	Fuel/Oxidizer Management Assembly
GC	Gas Chromatograph
G	Grams
IOP	Input/Output Processor
ISS	International Space Station
Kg	Kilogram
Mpa	Mega Pascal
N/A	Not Applicable
NASA	National Aeronautics and Space Administration
PDR	Preliminary Design Review
PI	Principal Investigator
SAR	Shared Accommodations Rack
SSP	Space Station Program
TBD	To Be Determined
UML	Universal Mounting Location

APPENDIX B MASS PROPERTIES EXAMPLE TABLE

B.1 Scope

The purpose of this appendix is to display a generic example the Mass Properties Summary Table.

B.2 Example of CIR Mass Properties Summary Table

	Assembly	Base Estimate	Percent of	Control	Control Mass	Percent of	Margin (Kg)	Installed During	Installed During	Manager Allotment
		(Kg)	Total	Factor	[Kg]	Total	(Control - Base)	Launch ?	Operation?	[Kg]
CIR Fully Populated Configuration	Optics Bench - Optics Bench Assembly	92.86	9.26%	1.03	95.99	8.73%	3.13	Y	Y	
	Optics Bench - Optics Bench I/F Hardware	33.84	3.37%	1.10	37.10	3.38%	3.26	Y	Y	
	Chamber - Chamber Assembly	138.85	13.85%	1.02	142.05	12.93%	3.20	Y	Y	
	FOMA	78.70	7.85%	1.03	81.02	7.37%	2.32	Y	Y	
	FOMA - FCU	14.42	1.44%	1.06	15.30	1.39%	0.88	N	Y	
	FOMA - Gas Chromatograph Launch Mass	9.39	0.94%	1.06	9.90	0.90%	0.52	Y	Y	
	FOMA - Gas Chromatograph Additional On-Orbit Mass	11.49	1.15%	1.16	13.31	1.21%	1.82	N	Y	
	Experiment Assembly - CIR Service Umbilical Set	5.84	0.58%	1.16	6.77	0.62%	0.92	Y	Y	
	Diagnostics - Color Camera	11.57	1.15%	1.12	12.92	1.18%	1.35	N	Y	
	Diagnostics - UV Camera	13.57	1.35%	1.12	15.27	1.39%	1.70	N	Y	
	Diagnostics - HiBMS Camera	11.31	1.13%	1.08	12.26	1.12%	0.95	N	Y	
	Diagnostics - Mid-IR Camera	11.94	1.19%	1.13	13.45	1.22%	1.51	N	Y	
	Diagnostics - HFR/HR Camera	11.00	1.10%	1.07	11.79	1.07%	0.79	N	Y	
	Diagnostics - Illumination	10.79	1.08%	1.12	12.04	1.10%	1.25	N	Y	
	Diagnostics - IPP A	18.16	1.81%	1.08	19.56	1.78%	1.41	N	Y	
	Diagnostics - 2 IPSUs	15.64	1.56%	1.16	18.11	1.65%	2.47	N	Y	
	FOMA - Bottle (3.8L)	10.07	1.00%	1.06	10.69	0.97%	0.62	N	Y	
	FOMA - Bottle (3.8L)	10.07	1.00%	1.06	10.69	0.97%	0.62	N	Y	
	FOMA - Bottle (3.8L)	10.07	1.00%	1.06	10.69	0.97%	0.62	N	Y	
	FOMA - Absorptive Filter (Large)	4.70	0.47%	1.06	4.99	0.46%	0.29	N	Y	
Common Systems	I/O Processor	29.14	2.91%	1.06	30.97	2.82%	1.82	Y	Y	
	ECS - Water Distribution & Control Assy	34.34	3.42%	1.06	36.46	3.32%	2.11	Y	Y	
	ECS - Air Thermal Control Assembly	60.18	6.00%	1.07	64.47	5.87%	4.28	Y	Y	
	ECS - Fire Detection & Suppression Assy	2.47	0.25%	1.08	2.68	0.24%	0.20	Y	Y	
	ECS - Gas Interface Assy	16.23	1.62%	1.06	17.23	1.57%	1.00	Y	Y	
	Rack - Doors Assembly	24.77	2.47%	1.06	26.29	2.39%	1.53	Y	Y	
	Rack - Rack-to-Station I/F Umbilical Set	10.66	1.06%	1.06	11.31	1.03%	0.66	N	Y	
PI	Chamber - Chamber Insert Assembly	40.00	3.99%	1.00	40.00	3.57%	0.00	N	Y	
	Diagnostics - PI-Specific Electronics	14.42	1.44%	1.00	14.42	1.18%	0.00	N	Y	
GFE	Electrical Power Subsystem	58.04	5.78%	1.00	58.04	5.28%	0.00	Y	Y	
	ARIS - Launch Condition*	61.06	6.09%	1.00	61.06	5.56%	0.00	Y	Y	
	ARIS - Additional On-Orbit Mass*	14.45	1.44%	1.00	14.45	1.31%	0.00	N	Y	
	SAMS Subsystem	0.85	0.08%	1.00	0.85	0.08%	0.00	Y	Y	
	Rack - Rack Assembly	11.90	11.16%	1.00	11.90	10.18%	0.00	Y	Y	
	Management Reserve				54.95	5.00%	54.95			
	GROSS TOTAL	1002.78		1.06	1098.96		96.18			0.00
	Integrated Rack Limit	804.20			804.20					
*ARIS Projected mass modified to reflect S684-10158 PIDS for ARIS paragraph 3.2.2.8, ARIS has total weight of no greater than 191 lbs. and launch weight of no greater than 138 lbs.										
		Hardware	Mass (Kg)	Margin						
	Mass Control Factor Explanation	Launch Configuration Base Mass	758.46	5.69%						
	5% - Preliminary mass obtained 10% - Vendor supplied data or Pro Engineer mass 15% - Preliminary design in process	Launch Configuration Control Mass	782.77	2.66%	Hardware	Base Mass (Kg)	Percent of Total	Control Mass [Kg]	Percent of Total	
	20% - Conceptual design in process	Operating Configuration Base Estimate	1002.78	-24.69%	CIR Total	809.47	80.72%	892.08	81.18%	
		Operating Configuration Control Mass	1098.96	-36.65%	PI Fully Populated Configuration	193.30	19.28%	206.88	18.82%	